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COMPARISON OF RESULTS OF TWO SIMULATIONS EMPLOYING FULL-SIZE VISUAL CUES FOR PILOT-CONTROLLED GEMINI-AGENA DOCKING

by Donald R. Riley, Byron M. Jaquet, Jack E. Pennington, and Roy F. Brissenden

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

An investigation involving seven astronauts as test subjects has been made to assess the overall compatibility of the results of two independent full-size simulations of pilot-controlled Gemini-Agena docking. One simulator (fixed base) employed a closed-circuit television system to display an image of the Agena target vehicle on a spherical screen. The other simulator (moving-base) used a dynamic full-size model of the Gemini spacecraft and a stationary three-dimensional target. A comparison of the results of the investigation in which only visual cues of the target vehicle were used for guidance information indicated that, after sufficient training, essentially the same results could be obtained from either simulator. Learning effects were found for both simulations; however, these effects were considerably more pronounced for the fixed-base simulator. Differences in the target markings and docking cones employed on the Agena models, a lack of three dimensions in the TV image, degradation of the visual cues due to the TV presentation, and the presence of the gravity-force angular cue in the moving-base simulator are partially responsible for this difference in learning effects. In addition to the simulator comparison, the docking results presented herein provide additional information on Gemini-Agena docking using the direct mode of control (on-off acceleration command system).

INTRODUCTION

Full-size six-degree-of-freedom simulations of the docking between the Gemini spacecraft and Agena target vehicle have been carried out at the Langley Research Center with both fixed- and moving-base simulators. The fixed-base simulator employed closed-circuit TV to provide the pilot a visual projection of the target vehicle whereas the moving-base simulator used a stationary full-size three-dimensional target model and a movable Gemini vehicle. Several independent investigations have been completed on each simulator. Some effects of spacecraft attitude control mode, control power, jet malfunctions, target lighting, and target motion on pilot-controlled docking are documented in references 1 to 8.

To assess the general compatibility of the results obtained from the two simulators, a short investigation was made in which similar targets, equivalent equations of motion, and identical hand controllers were employed in both simulations. Seven astronauts who had not flown either simulator and who were, as yet, untrained in Gemini-Agena docking were utilized as the test subjects. Docking flights were made from an initial range of 125 feet (38.1 meters) with only out-of-the-window observation of the target vehicle for guidance information. The data from this investigation provide a basis for comparing the two simulators and, in addition, provide some information on the Gemini-Agena docking task using the direct (on-off acceleration command) mode for spacecraft attitude control.

SYMBOLS

The system of axes employed in the present study is shown in figure 1. The units for the physical quantities used herein are presented in both the U.S. Customary System and in the International System.

F_X, F_Y, F_Z — total forces on spacecraft in direction of reference X-, Y-, and Z-axes, respectively, lbf (newtons)

$I_{X,b}, I_{Y,b}, I_{Z,b}$ — moments of inertia about Gemini body axes, slug-ft^2 (kilogram-meters^2)

$M_{X,b}, M_{Y,b}, M_{Z,b}$ — moments about Gemini body axes, ft-lbf (newton-meters)

m — Gemini mass, slugs (kilograms)

p,q,r — angular rates about Gemini body axes, rad/sec or deg/sec

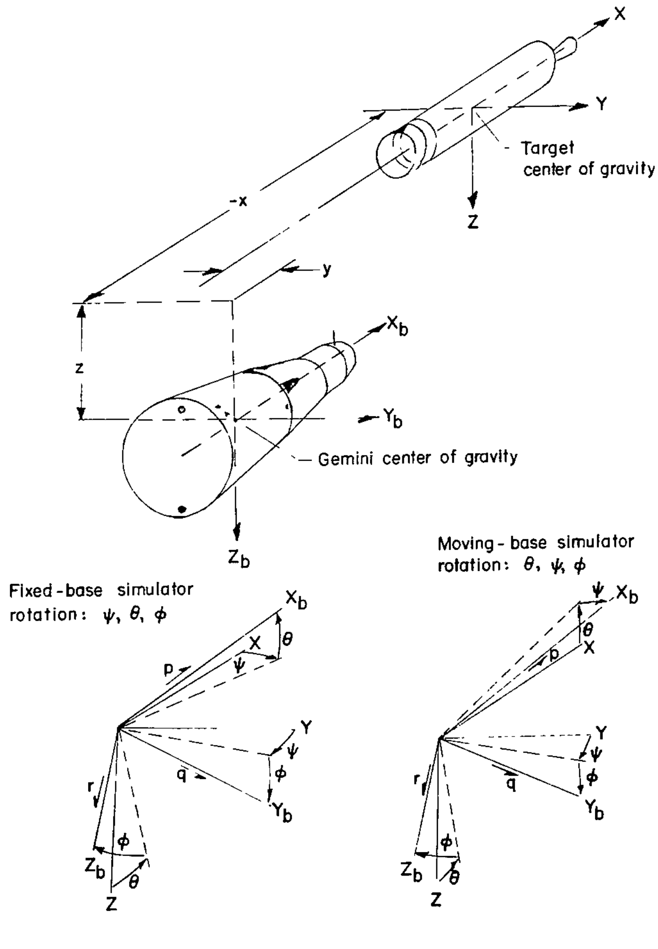


Figure 1.- System of axes employed.

X,Y,Z right-hand body-axis system located at midlength of Agena (reference axes); see figure 1

X_b,Y_b,Z_b right-hand body-axis system located at Gemini center of gravity; see figure 1

x,y,z distances along reference X-, Y-, and Z-axes, respectively, ft (meters)

ψ,θ,ϕ Euler angles relating position of Gemini body axes and Agena body axes, deg or rad; see figure 1

Subscripts:

n relative conditions of spacecraft nose with respect to target docking cone at flight termination

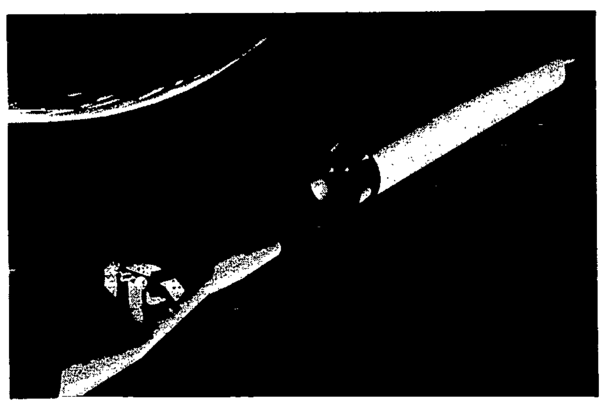
o initial conditions

tol tolerance

A dot over a symbol denotes a derivative with respect to time.

GEMINI-AGENA VEHICLES

The Gemini spacecraft is a second-generation two-man vehicle designed for long-duration space flights, extravehicular operations, and pilot-controlled rendezvous and docking in space. Figure 2(a) is an artist's illustration of the vehicle shortly before the docking. The spacecraft consists of reentry and maneuvering units which are joined near the heat shield which is just behind the astronauts. The maneuvering unit contains all the engines used during the docking phase. The propulsion system (fig. 2(b)) consists of eight attitude-control jets and eight translation jets, all of which use hypergolic fuel. Proper combinations of the eight attitude jets are used to control the vehicle in yaw, pitch, and roll. For translation, pairs of jets provide fore and aft movement: single jets supply vertical



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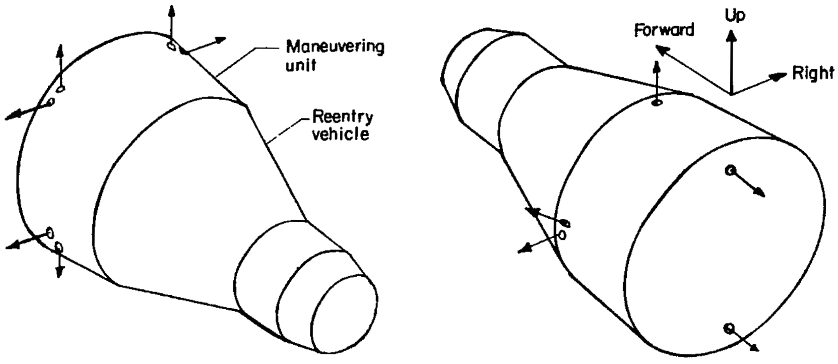
(a) Artist's illustration of Gemini and Agena near contact.

Figure 2.- Gemini spacecraft and Agena target vehicle.



(b) Illustration of Gemini orbital attitude and maneuvering system. Arrows indicate individual jets.

Figure 2.- Concluded.

and lateral maneuvering. All the jets are located rearward of the spacecraft's center of gravity. Because of this rearward jet location, control cross coupling occurs; that is, vertical and lateral control inputs also produce spacecraft pitch and yaw motions. Pitch and yaw control inputs similarly produce vertical and lateral translations.

L-64-4307
(a) Photograph of Gemini mockup and associated drive system.

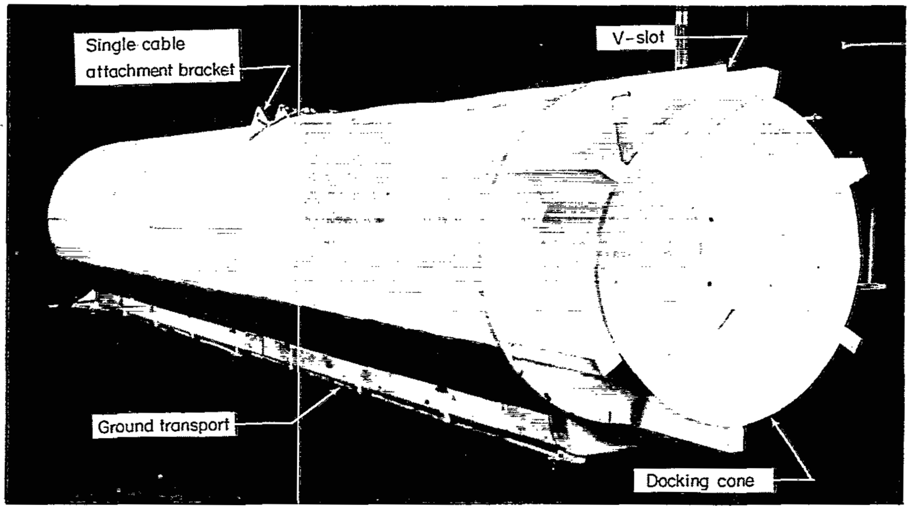
Figure 3.- Moving-base docking simulator.

For docking, the Agena target vehicle has a 5-foot (1.52 meter) diameter, shock-mounted cone on the front which serves to channel the Gemini nose to the Agena coupler for latching and rigidizing the two vehicles. The V-shaped slot in the Agena docking cone and the indexing bar on the Gemini provide roll alinement for the latching mechanism.

CHARACTERISTICS OF SIMULATORS USED

Moving-Base Simulator

The moving-base simulator (fig. 3) consisted of full-size models of the reentry section of the Gemini spacecraft and the Agena target vehicle, three transport and three angular drive systems, and a general-purpose analog computer. The Gemini vehicle (fig. 3(a)) was mounted in a hydraulically driven gimbal system which provided three degrees of angular freedom. The vehicle and gimbal system were, in turn, suspended by eight supporting cables from an electrically driven overhead carriage system. A dolly mounted on the main carriage provided lateral motion while the whole system moved longitudinally. A cable drum on the dolly was used to reel and unreel the cables for vertical motion. The cable arrangement and attachment angles were designed specifically to prevent pendulous motion. The simulator allowed the pilot to move in six degrees of freedom which he controlled from the vehicle through the ground-based analog computer. Maximum operating volume of the simulator permits the vehicle to travel 150 feet (45.7 meters) longitudinally, ±20 feet (±6.09 meters) vertically, and ±6 feet (±1.83 meters) laterally. A detailed description of the design and operational capabilities of the facility is given in reference 9.



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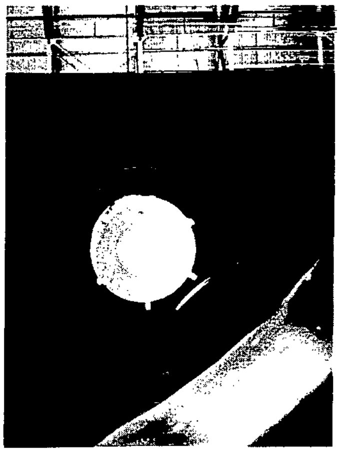
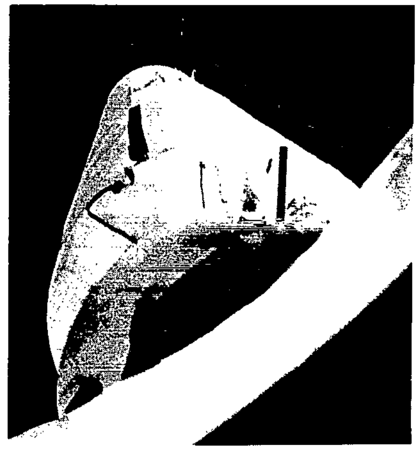
(b) Agena target model prior to being hoisted.

Figure 3.- Concluded.

The full-size Agena target model (figs. 3(b) and 4) did not move. It was suspended by a single cable from the ceiling of the Langley aircraft hangar 30 feet (9.14 meters) above the floor and held in place midway between the main carriage tracks by four stabilizing cables. The model was internally illuminated for simulator operation at night in order to provide a diffuse target comparable to the brightness of the TV projection used in the fixed-base simulator.



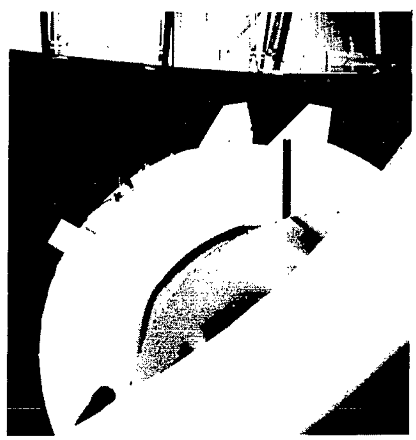
(a) 30 feet (10.14 m) before contact; axes alined.



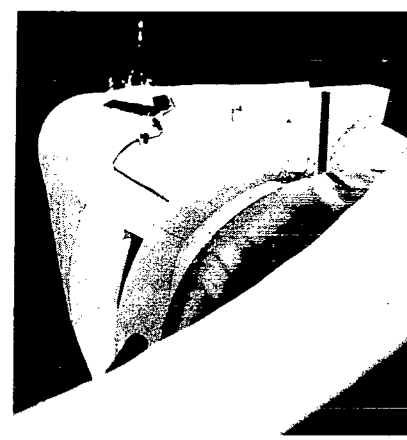
(c) At contact; pitch angle = -10^{0}.

(e) At contact; yaw angle = -10^{0}.

(b) 10 feet (3.05 m) before contact; axes alined.



(d) At contact; pitch angle = 10^{0}.



(f) At contact; yaw angle = 10^{0}.

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Figure 4.- Photographs of target of moving-base simulator taken during daylight from the left Gemini window, showing visual scene for various Gemini orientations.

Fixed-Base Simulator

The fixed-base simulator (fig. 5) consisted of a general-purpose analog computer, a modified U.S. Air Force aerial gunnery trainer, type F-151, and a full-size wooden mockup of the Gemini spacecraft housed within a 20-foot-diameter (6.09-meter-diameter) spherical projection screen. Included in the gunnery trainer was a standard 525 line closed-circuit television system which was used to project a full-size image of the Agena target on the screen. Raster size as measured on the projection sphere was 76 by 76 inches (193 by 193 centimeters). A small-scale model of the Agena vehicle was

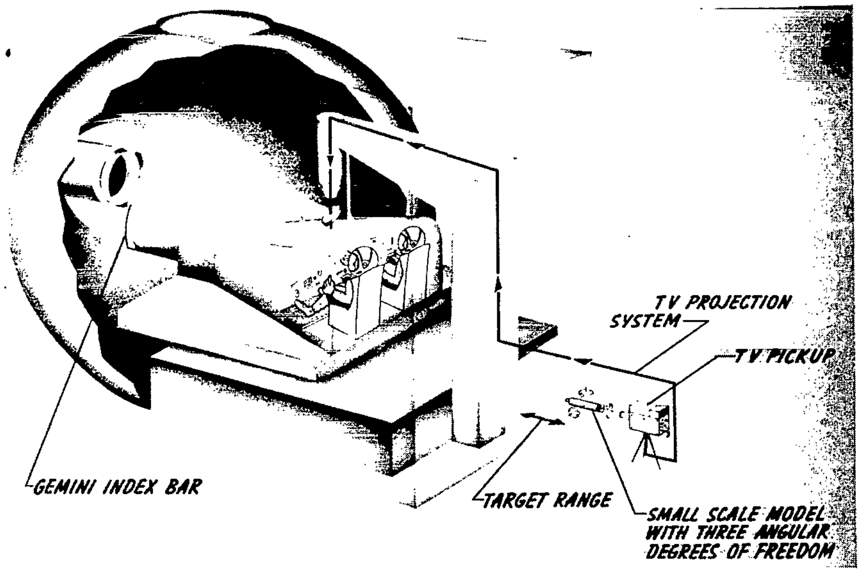

Figure 5.- Artist's illustration of fixed-base docking simulator.

mounted in a gimbal box in front of the television camera (fig. 6). The model translated along the camera axis and rotated about its center with three angular degrees of freedom. The camera video signal was transmitted to the projection system mounted vertically above the pilot (fig. 7). The target image (fig. 8) was projected on a flat mirror that was servodriven about two axes and located at the center of the sphere a short distance above

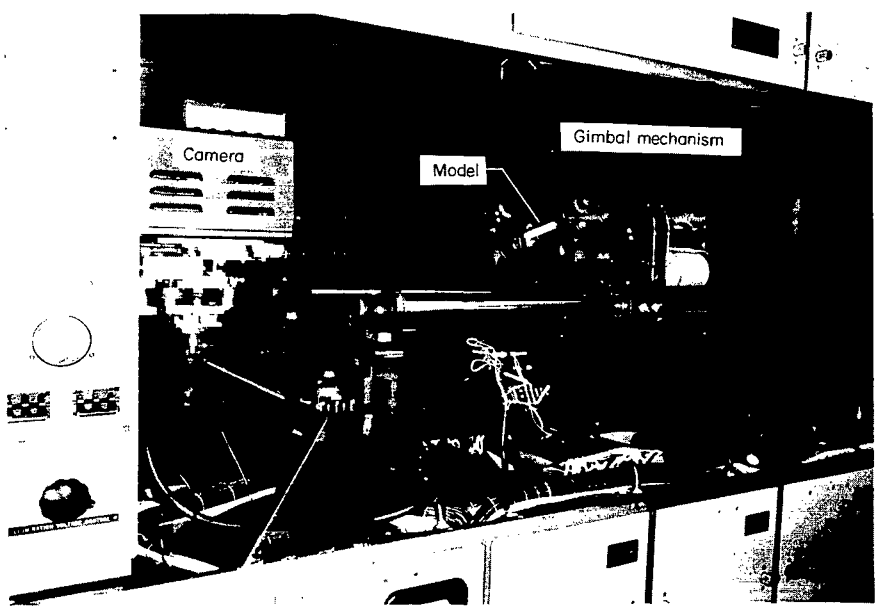

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Figure 6.- Television pickup camera, Agena model in gimbal box, and range drive system.

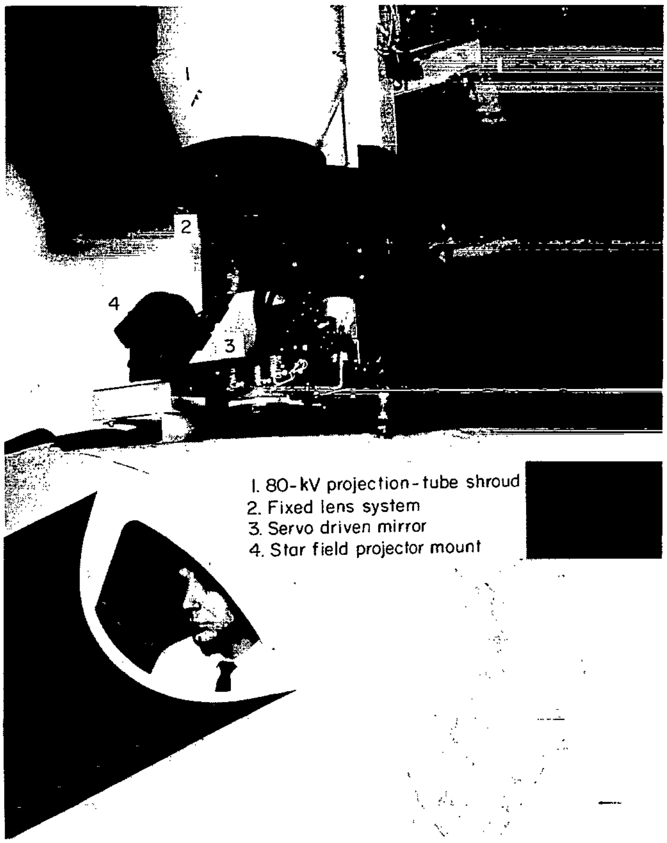

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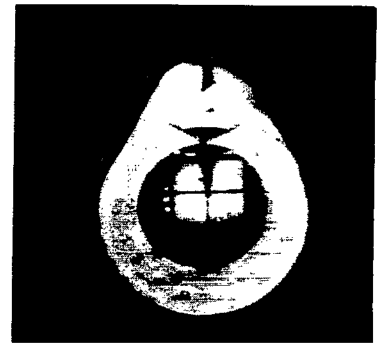
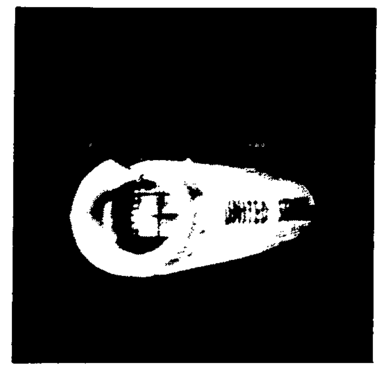
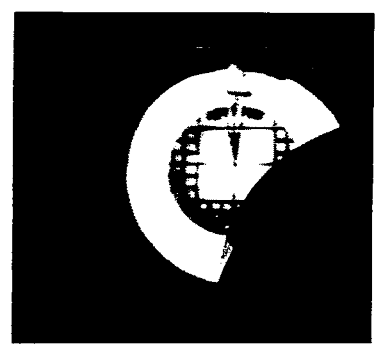
Figure 7.- External view of Gemini mockup, with television projection system and two-axis mirror above pilot's head.



(a) Gemini displaced above target.



(b) Gemini displaced to right of target.



(c) Gemini and Agena center lines alined a short distance from contact.

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Figure 8.- Photographs of pilot's view of target image displayed on spherical screen of fixed-base simulator, showing target markings employed in simulation. Large squares in photos represent ±1-foot (±0.305-m) docking tolerance.

the pilot's head. In order to account for the distance between the pilot's eyes and the mirror, a mechanical parallax correction was used so that the mirror positioned the target image on the screen at the appropriate azimuth and elevation angles. The image was focused on the screen by means of a fixed-lens system located between the mirror and projector. Full six-degree-of-freedom motion was simulated by means of the combined model and mirror movements. Pilot-control signals were sent to the analog computer which solved the equations of relative motion between the spacecraft and target. The computer outputs were converted in the gunnery trainer to line-of-sight range, target angular aspect about the line of sight, and spatial location. These signals were used to drive the appropriate servomechanisms for the display. The operating volume of the simulator as scaled permitted translational maneuvers up to maximum displacements of 300 feet (91.4 meters) longitudinally and ±150 feet (±45.7 meters) vertically and laterally.

Commonality of Simulators

Features common to both the fixed- and moving-base simulators are itemized as follows –

Both simulators:

(1) Are flown from the left-hand seat and use only visual observation of target for guidance information.

(2) Use equivalent equations of motion.

(3) Have the same piloting task and initial test conditions.

(4) Use the direct (acceleration command) mode for spacecraft attitude control.

(5) Use the same hand controllers.

(6) Use a specified flight termination point (identified as the point where the index bar is in the front plane of the docking cone).

(7) Have identical spacecraft nose lengths and index-bar locations.

(8) Use the same window-frame shape and an unlighted index bar.

(9) Use similar full-size targets. (Although not identical, both targets were models of the Agena.)

(10) Position the pilot vertically for comfort in a 1g field instead of canted to the side as in the actual spacecraft.

It should be noted that a nose length longer than that of the actual Gemini spacecraft with the index bar positioned at the tip of the nose was employed in both simulations. This setup permitted placing the index bar in the fixed-base simulator against the 10-foot (3.05 meter) radius screen and thus eliminated complicated parallax corrections. (The distance from the pilot's eyes to the index bar, measured along the center line, was 9.73 feet (2.97 meters) in the simulators compared with 7.94 feet (2.42 meters) in the actual spacecraft.)

Differences Between Simulators

Differences between the two simulators are as follows:

1. Fixed-base versus moving-base cockpits (gravity-force angles were constant on the pilot in the fixed-base simulator and variable with cockpit attitude in the moving-base simulator)
2. TV projected target image versus real three-dimensional target
3. Target markings and docking rings used (see figs. 3, 4, and 8)
4. Control response characteristics (see following section)

Response Characteristics

Computer outputs of linear and angular displacements were used to drive the equipment of both simulators. Comparison of the response characteristics of the two simulators were carried out from tests performed by using step-displacement inputs. Typical step-input results indicate a time lag from input initiation to display movement of 0.10 second in the fixed-base simulator. For the moving-base simulator (which had larger mass and inertias) values from 0.20 to 0.40 second were obtained, depending on the particular drive. Initial time lag was believed to be of particular interest since it is the parameter most noticeable to the pilot. While the fixed-base simulator was the quicker reacting of the two machines, the difference became noticeable to a pilot only after he acquired some proficiency in the docking task.

EQUATIONS OF MOTION

The basic equations of motion used in the two simulations were identical. The force equations were written with respect to a reference set of axes located in the Agena with the origin at the target's center of gravity. (See fig. 1.) If a vehicle of constant mass is assumed, the equations are as follows:

$$\frac{F_X}{m} = \ddot{x}$$

$$\frac{F_Y}{m} = \ddot{y}$$

$$\frac{F_Z}{m} = \ddot{z}$$

The moment equations were written with respect to a body system of axes with the origin located at the center of gravity of the Gemini spacecraft. The center of gravity, mass, and moments of inertia were chosen to correspond to a one-half-fuel-load condition for the parachute configuration. The moment equations used are

$$M_{X,b} = \dot{p}I_{X,b} + qr\left(I_{Z,b} - I_{Y,b}\right)$$

$$M_{Y,b} = \dot{q}I_{Y,b} + pr\left(I_{X,b} - I_{Z,b}\right)$$

$$M_{Z,b} = \dot{r}I_{Z,b} + pq\left(I_{Y,b} - I_{X,b}\right)$$

To solve the three translational equations of motion, the forces F_X, F_Y, and F_Z acting on the Gemini spacecraft in the direction of the reference axes are required. These forces were obtained by using the forces generated along the Gemini spacecraft body axes by the various thrusters and transformed through the use of an Euler angle matrix. Different matrices were required in the two simulations because of the different order of Euler angle rotations used. In the fixed-base simulator, the model gimbal arrangement was such that the standard order of Euler rotations ψ, θ, and ϕ were employed. In the moving-base simulator the gimbal arrangement supporting the Gemini vehicle required rotations of the order θ, ψ, and ϕ. To assure equivalence of computer programs for the two simulators, static and dynamic comparisons of the solutions to the equations were made with an independent digital solution.

SCOPE OF SIMULATION

Participants

Seven astronauts who had not flown either simulator were used as the test subjects. Although this was the first experience for each of the seven in controlling the Gemini vehicle during docking, several astronauts had some previous experience using the attitude hand controller in reentry simulations. None of the astronauts had ever used the translation controller. In addition, several astronauts had participated in general docking studies, but none involving the Gemini dynamics.

At the completion of the test program for the astronauts, one Langley research pilot, who had over 400 Gemini-Agena docking flights on the moving-base simulator but none in the fixed-base simulator participated in a portion of the same test program as the astronauts on the fixed-base simulator. His results on the fixed-base simulator are included herein.

Pilot's Task

In both simulations the pilot flew from the left seat and used only out-of-the-window observation of a fully illuminated target for guidance information. His task was to take control of the Gemini at the initial conditions and to maneuver the vehicle until the nose began to enter the docking cone within prescribed tolerances. The pilot could use whatever technique he preferred without particular regard for fuel consumed or flight time used.

Docking tolerances not to be exceeded at the flight termination point were:

±1-foot (0.305-meter) vertical and lateral displacement of Gemini nose and docking cone centers

±10° relative angular misalinements (ψ, θ, and ϕ) about each axis

1.5 ft/sec (0.46 m/s) longitudinal contact velocity

±0.5 ft/sec (0.15 m/s) vertical and lateral velocity between Gemini nose and docking cone

The flight termination point was the longitudinal distance which would place the Gemini index bar in the front plane of the docking cone. A docking flight was considered out of tolerance if any one of the variables exceeded the specified tolerances. It should be noted that in an actual space mission some out-of-tolerance conditions might not cause an unsuccessful mission but may simply require additional spacecraft maneuvering following initial contact to achieve in-tolerance conditions. In the simulations, docking flights were terminated when the flight termination point was reached and additional maneuvering was not permitted.

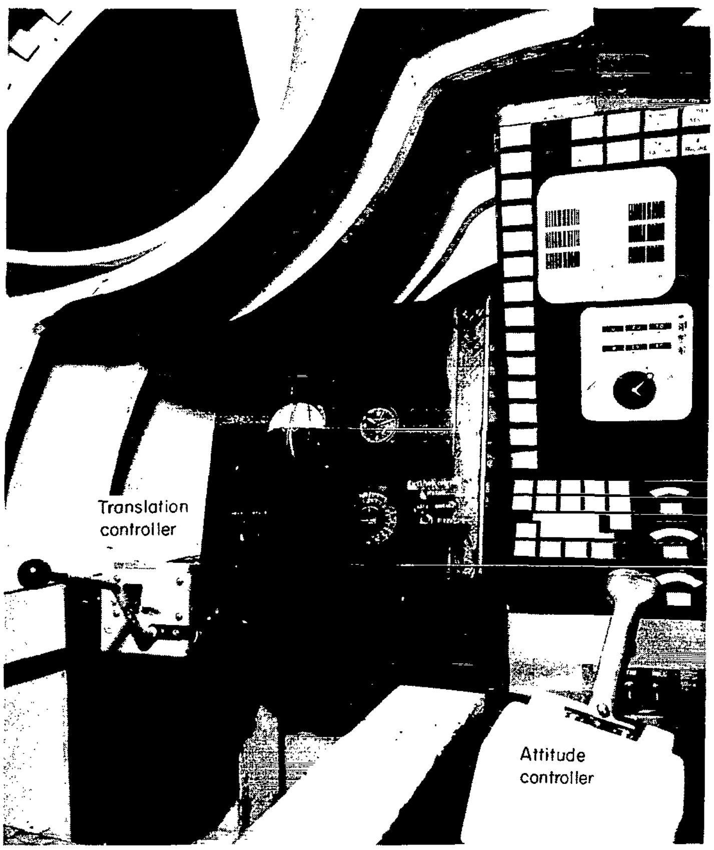

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Figure 9.- Internal view of Gemini mockup of fixed-base simulator showing prototype hand controllers used in both simulations. (Instrument panel was covered for test program.)

Hand Controllers

Prototype Gemini hand controllers were used in both simulators and are shown installed in the fixed-base simulator in figure 9. With his left hand the pilot moves the translation controller fore and aft, left and right, and up and down which results in the activation of the corresponding spacecraft maneuver thrusters. The translation controller actually had a 2-inch-diameter (5.08-centimeter-diameter) spherical knob instead of the smaller one shown in the figure. The deflection characteristics of the translation controller were measured and are shown in figure 10. Looseness, indicated by the displacements along the zero force axes, and some binding, indicated by the discontinuities in the force-displacement curves, can be seen for this particular controller. The translation, or maneuvering, system provided maximum thrust when the controller deflection was such that the microswitches were engaged. (See fig. 10.) The attitude controller, operated by the right hand, enabled the pilot to roll, pitch, and yaw the spacecraft. Deflection characteristics of the attitude controller are shown in figure 11. The direct mode of attitude control was an on-off system providing maximum thruster outputs when controller deflection exceeded 25 percent of the total available deflection. Prototype Gemini instruments shown in figure 9 were used only for simulator check-out and then were covered for the test program. An evaluation of the hand controllers and instruments for the docking task is presented in reference 5.

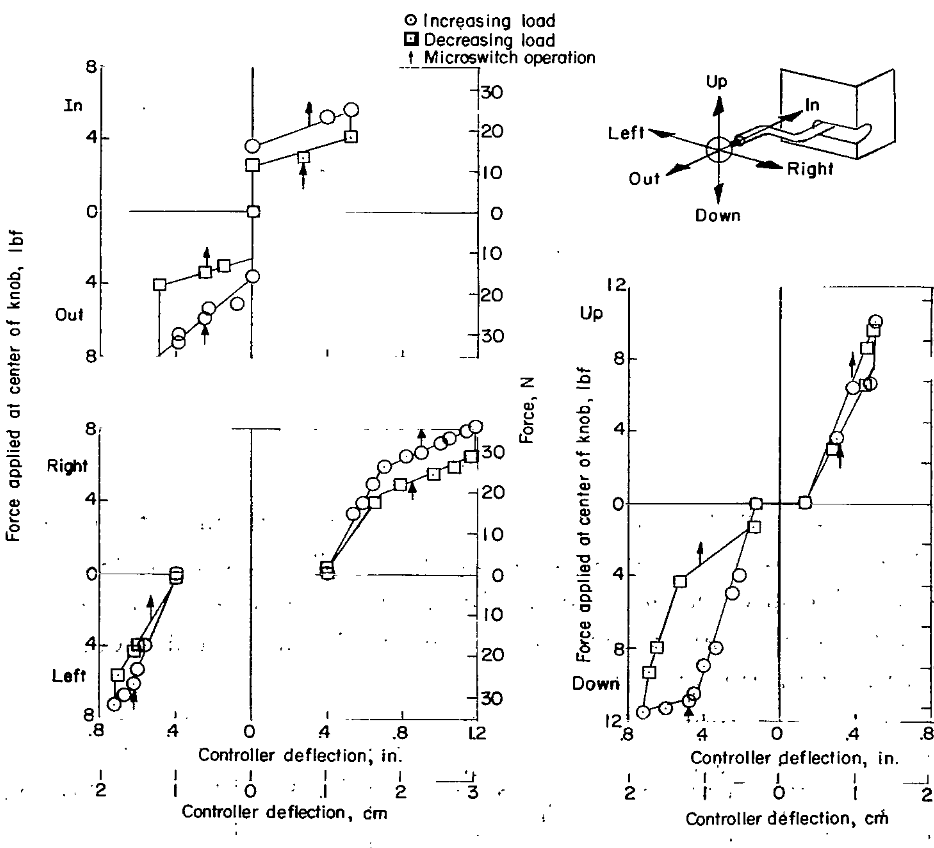


Figure 10.- Characteristics of translation controller.

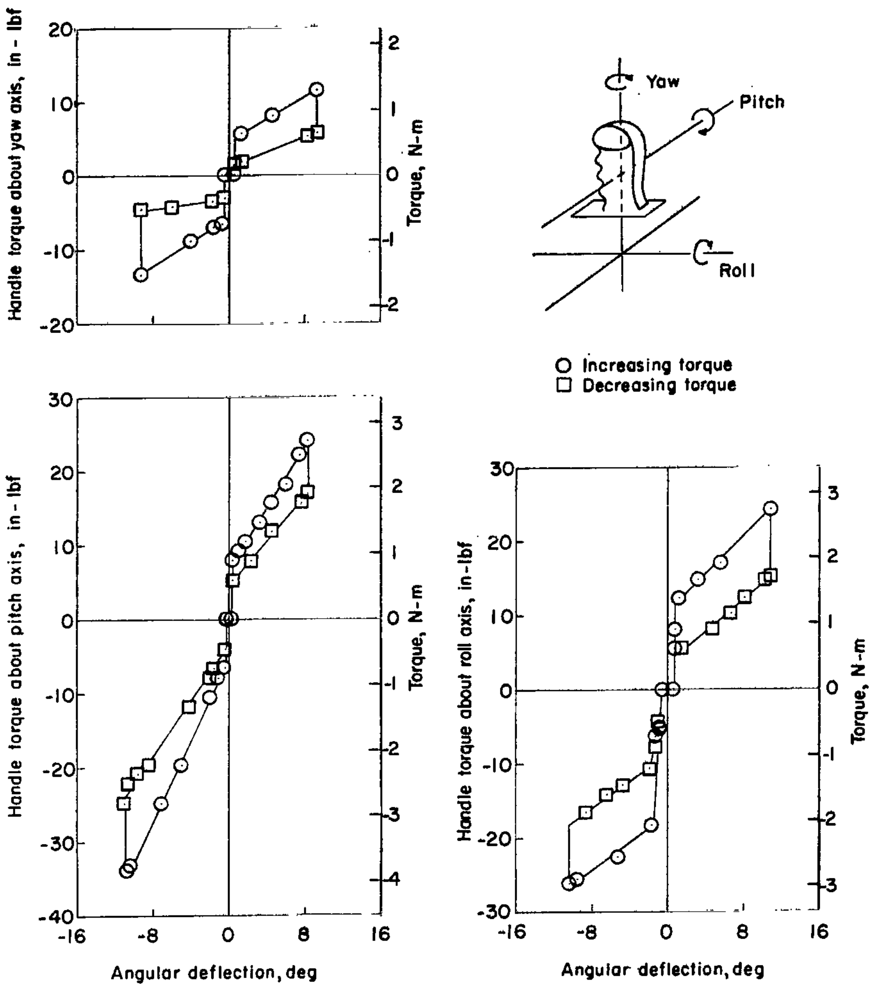


Figure 11.- Characteristics of attitude controller. (Arrows indicate positive direction of handle torques and deflections.)

Initial Conditions

The same sequence of initial conditions was used for all subjects in both simulators. Longitudinal displacement x_o was always -125 feet (-38.1 meters) (see fig. 1), and initial Gemini translation velocities and angular rates were set equal to zero. The linear and angular displacements were varied for successive flights by using combinations of the values shown in the following table:

x_o		y_o		z_o		ψ_o, deg	θ_o, deg	ϕ_o, deg
ft	m	ft	m	ft	m			
-125	-38.1	0, ±5	0, ±1.52	0, ±5	0, ±1.52	0, ±10	0, ±10	0, ±10

Values for displacements and attitudes were selected so that the target vehicle was entirely visible to the pilot at flight initiation.

Test Procedure

To perform the tests, the astronauts were grouped in pairs. One astronaut performed the required docking flights on the fixed-base simulator from 9 a.m. to 4 p.m. At the completion of these flights, both hand controllers were removed from the fixed-base simulator and installed in the moving-base simulator. The second astronaut performed the required flights in the moving-base simulator from 5 p.m. to 11 p.m. The moving-base simulator was operated at night in order to eliminate extraneous visual cues from the hangar structure. (See fig. 4.) At the completion of these tests, the controllers were reinstalled in the fixed-base simulator and the procedure was repeated the next day with the astronauts changing simulators. A debriefing period followed each test session. Only one simulator was flown by any given astronaut in one day. Four of the astronauts flew the fixed-base simulator first while the remaining three flew the moving-base simulator first.

The test programs, which were identical for both simulations, were divided into three major parts; a training session, a data session, and an extra session. After six successive docking flights on the first simulator, four successive in-tolerance flights constituted completion of the training phase if the subject and test engineers concurred. The six preliminary docking flights were not required for the second simulator; however, accomplishment of four successive in-tolerance flights was required. For the data session, nine docking flights were made. Then, depending on the session time remaining, a number of extra docking flights were made. In the case of the fixed-base simulation, sufficient time was usually available to permit obtaining a second set of six data flights.

Since this was the first exposure to the Gemini-Agena docking task by the astronaut participants, completion of the test program on each simulator was arranged so as to leave a short period of operation time available for additional docking familiarization. During this short period, the astronauts were given one or two darkside docking flights with and without visual aids mounted on the target and several thruster failure flights on the moving-base simulator. On the fixed-base simulator, the initial conditions were changed to $x_o = -275$ feet (-83.82 meters), $z_o = 75$ feet (22.87 meters), and $y_o = 100$ feet (30.5 meters). Several flights were made with and without the instruments shown in figure 9 and a few flights were made with the primary (rate-command) attitude control mode. Although the data of these supplemental flights on both simulators are too meager for presentation herein, the astronaut comments on them are included.

DISCUSSION OF RESULTS

Method of Analysis

The numerical measurements taken during the investigation are presented herein in three sections: (1) Task Performance, (2) End Conditions, and (3) Time-History Results. The section entitled "Task Performance" examines the overall accomplishment of the docking task by inspecting the successfulness of the task achievement and the fuel and time required for the maneuver. The section entitled "End Conditions" presents the terminal values recorded for the flight variables and in the section entitled "Time-History Results" the overall docking maneuver from flight initiation to termination is examined briefly by means of maximum and minimum values of the flight variables, some integrated averages, and fuel expended at various points along the trajectory. The division of the participants into two groups, those flying the fixed-base simulator first and those flying the moving-base simulator first, and the division of the test program into its three parts (training, data, and extra flights) was employed. By dividing the subjects into two groups initially and comparing results after flying one simulator and then after flying the other simulator, the compatibility of the results of the two simulations can be ascertained. (Detailed analyses of the data to evaluate several effects, such as the transferability of training between simulators, was attempted. The significance of such results was questionable because of the large scatter of the data points, particularly for the fixed-base simulation and the fact that group differences cannot be separated from the data. Consequently, the results of these analyses are not included.) Pilot comments are contained in a section following the numerical measurements (for detailed questions and answers see appendix A) and an overall summation of the simulator comparison is presented in a section entitled "Evaluation."

Task Performance

Successful task achievement.- The primary piloting task of the docking flights was to achieve end conditions within the specified tolerances. Task achievement results are presented in figure 12 in the form of learning and experience curves for the two groups of astronauts, those flying the fixed-base simulator first (four-astronaut group) and those flying the moving-base simulator first (three-astronaut group). The abscissa scale, chosen to minimize the scatter of the data, simply consists of subdividing each subject's total number of docking flights into groups of three successive flights (one unit of experience). Differentiation between training and data flights was, of course, ignored.

From an examination of the results of figure 12, two general observations of the data can be made. By tracing each group's experience separately through both simulators, an initial observation is the apparent continuity of the results (in the manner of a normal learning curve) in the direction fixed- to moving-base (four-astronaut group) whereas a large discontinuity exists for the moving- to fixed-base data (three-astronaut group). However, upon further examination of the data, the second observation is that a similarity in the shapes of the curves exists for a given simulation regardless of whether they were for the first or second simulator flown. In fact, very nearly identical results were obtained for the two groups of astronauts on the moving-base simulator. For the fixed-base simulator, comparable trends in the data were obtained. These primary task results definitely indicate a difference exists between the two simulations and that it is more difficult to achieve the desired end conditions with the fixed-base simulator.

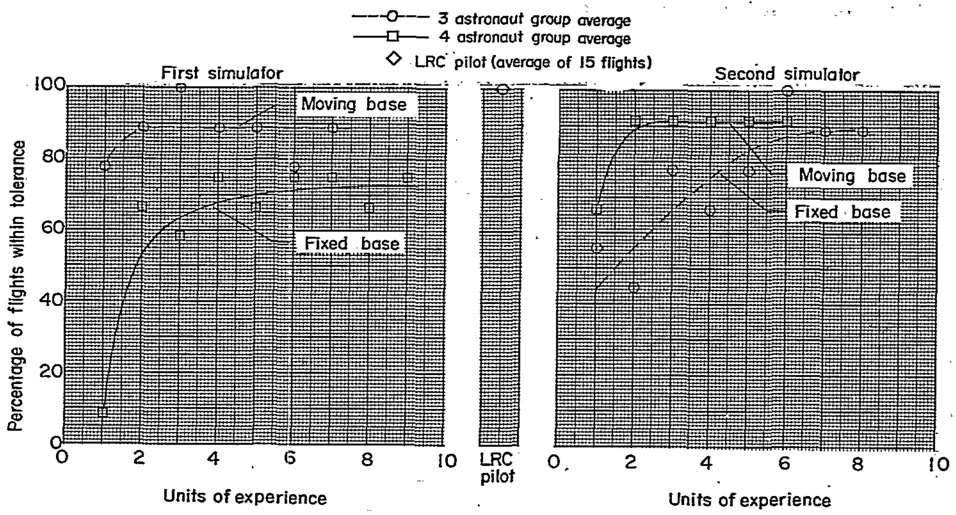


Figure 12.- Learning curves for successful task achievement obtained by the two groups of astronauts (each unit of experience per astronaut consists of three successive docking flights).

Since the data of figure 12 show a difference between simulation results, an examination of the unsuccessful docking flights of figure 12 was made to ascertain which design tolerances had been exceeded. These results, shown in figure 13, illustrate that the difficulty experienced in the fixed-base simulator by both astronaut groups was in meeting the angular alinement tolerances. In addition, a number of flights were not completed (lost) because the spacecraft attitude angles became so large that the target was completely lost from view. These flights were usually among the first flown.

Difficulties in angular alinement may be a manifestation of a boresight problem. The prominence of longitudinal stringers and the smaller diameter docking cone used in the moving-base simulation (figs. 3 and 4) which permitted a view of the docking cone against the tank body may have provided additional boresight information not available from the docking cone configuration used in the fixed-base machine. Degradation of the visual cues due to the projected TV presentation (such as raster lines and fuzziness of detail) also were an adverse influence. It should be noted that the achievement of desirable terminal conditions is dependent to a large extent on the maneuvers executed in the final few feet of separation. The lack of three dimensions in the visual display of the fixed-base simulator resulted in an indeterminateness about the flight termination point that adversely affected the pilot's estimation of the range-to-go when close to the target. This situation in the presence of strong control coupling would influence the maneuvering at short ranges that could contribute to the out-of-tolerance angular alinements experienced on the fixed-base simulator. Other than the difference in visual cues the better angular alinement performance of the moving-base simulator may have been influenced by the presence of the gravity-force angular cue and possibly by greater motivation resulting from being in the moving vehicle, particularly during the initial phases of learning. (See answers to questions 3, 4, 9, 14 to 19, 26, 30, and 33 in appendix A.)

Astro group	Simulator	Total number flights made	Number flights out-of-tolerance
4	Fixed	99	42
	Moving	65	7
3	Fixed	71	23
	Moving	57	8

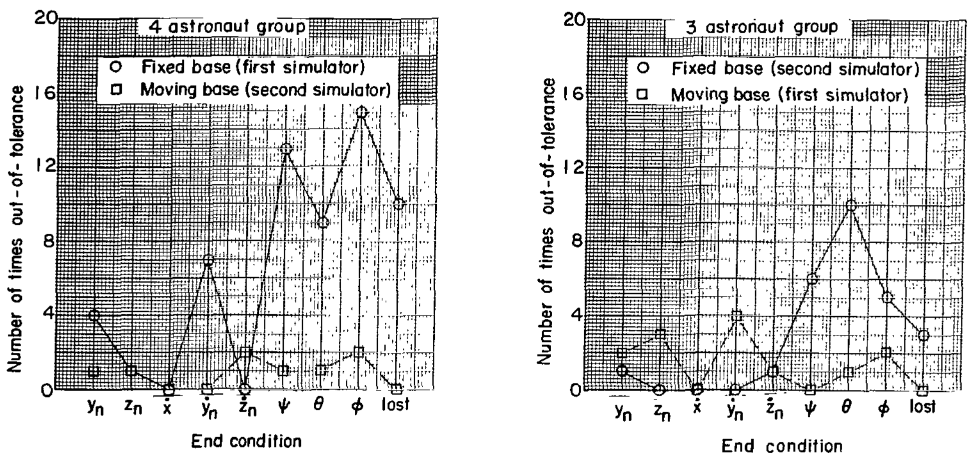


Figure 13.- Number of times a given component was out of tolerance at flight termination for the unsuccessful docking flights of figure 12. (Note, more than one component can be out of tolerance for a given flight.)

It is significant that the task was difficult to perform because of control coupling. Pilot unfamiliarity with both the task and vehicle dynamics could be expected to accentuate the effects of simulator differences and to produce differences in the terminal conditions. The research pilot who was highly skilled in Gemini dynamics (approximately 400 previous flights on the moving-base simulator) achieved 100-percent success in the 15 flights on the fixed-base simulator. This was his first experience using this simulator. Prior experience with several other research pilots who were assigned to fly a given simulator exclusively indicates that about twice the experience shown in figure 12

(80 to 100 flights) was required on either simulator in order to master control cross-coupling effects and to achieve consistent performance levels above 95 percent. On the basis of the present research pilot's results and prior knowledge, additional experience with the vehicle dynamics and with the docking problem appears to relegate to the early portions of the learning curve the difficulties due to the simulator differences encountered herein. It is of interest to note that at the completion of the flights on the second simulator, sufficient experience in control coupling and in docking apparently had been achieved so that the value of percent success was about the same for both simulators.

Fuel and flight time.- Total fuel used and flight time required to accomplish the docking flights are presented for both astronaut groups in figures 14 and 15 in the form of learning and experience curves comparable to those of figure 12. The rapid decrease in both fuel consumption and flight time with increasing experience is evident for both astronaut groups flying their first simulator. This result is as expected. Of interest, however, is that upon changing simulators, both groups show initial increases in fuel used and time required for task accomplishment. These increases indicate that an initial period of adjustment is required by the pilot for both simulators. Also of interest is the fact that the levels of fuel consumption and flight time achieved at the completion of the flights in each simulator are nearly the same. The values, in addition, approach the performance level of the more experienced research pilot and indicate the achievement of a reasonable degree of proficiency in the fuel and flight-time expenditures for the docking task with training.

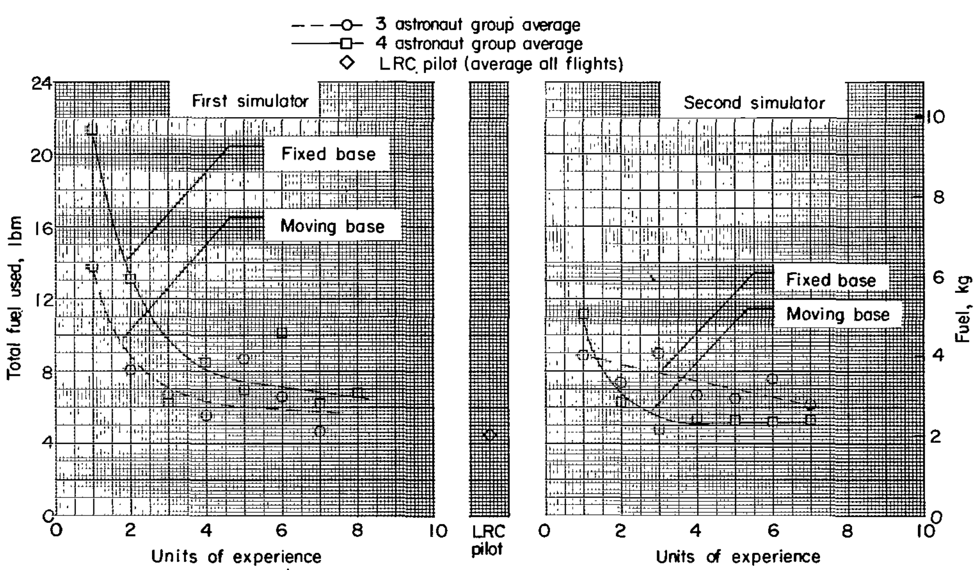


Figure 14.- Learning curves for total fuel used by the two groups of astronauts performing docking flights from 125 feet (38.1 m) (each unit of experience per astronaut consists of three successive docking flights).

The total fuel results have been separated into fuel used for translation and fuel used for attitude control. These results (fig. 16) show that increases in both fuel components occur initially when the subjects changed simulators. The relationship between

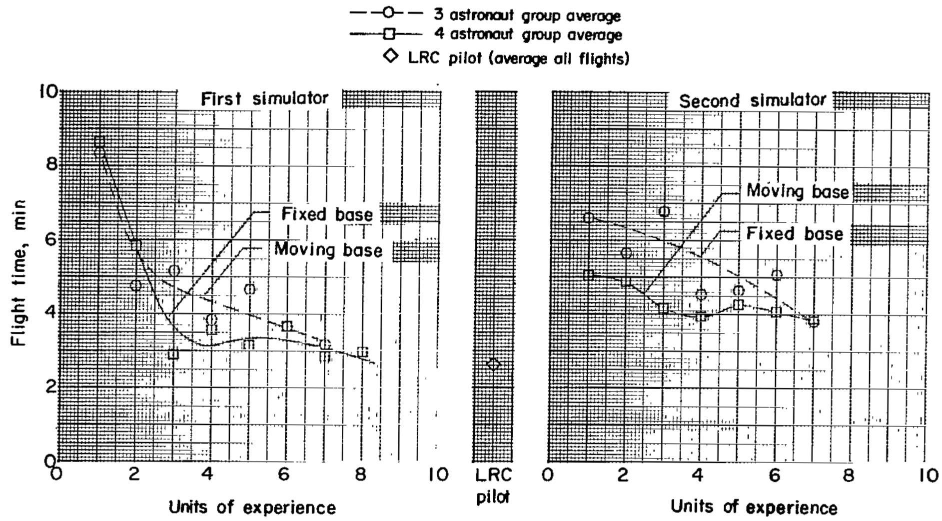


Figure 15.- Learning curves for flight time required by the two groups of astronauts performing docking flights from 125 feet (38.1 m) (each unit of experience per astronaut consists of three successive docking flights).

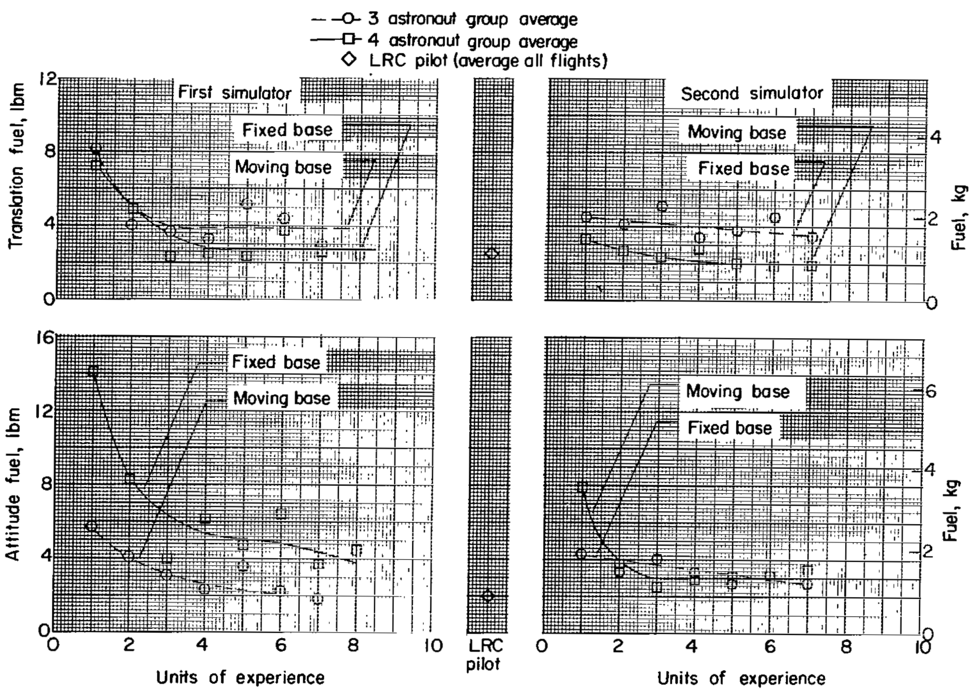


Figure 16.- Components of total fuel used for translation maneuvering and for spacecraft attitude control (each unit of experience per astronaut consists of three successive docking flights).

the attitude and the translation fuel used (fig. 17), although different for the two astronaut groups, remained the same for a given group on either simulator. Some verification other than pilot comment is thus obtained that the same technique was used on both simulators by a given group.

End Conditions

Analyses of the terminal values were carried out for each of the different flight variables, and comparisons of the fixed- and moving-base simulator results were made. A number of similarities and some differences were noted in the comparisons. The significance of these similarities and differences is difficult to evaluate when examining each variable independently. A more realistic appraisal would be to consider a combination of end conditions similar to those required for task accomplishment. By using those variables for which docking-cone tolerances were specified, a task magnitude factor (TMF) was defined by the equation shown in figure 18 where the absolute value of each term is used. Longitudinal velocity $\dot{x}$ was not included because achievement of

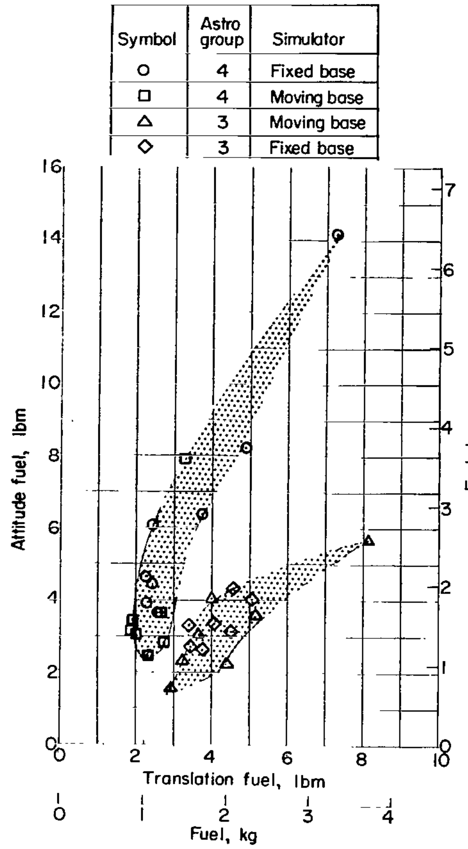


Figure 17. Fuel used for attitude control as a function of fuel used for translation maneuvering. Data points obtained from learning curves of both astronaut groups on each simulator.

For a given flight, task magnitude factor (TMF) is defined as

$$\mathrm{TMF} = \frac{1}{7}\left[\left|\frac{\psi}{\psi_{tol}}\right| + \left|\frac{\theta}{\theta_{tol}}\right| + \left|\frac{\phi}{\phi_{tol}}\right| + \left|\frac{y_n}{y_{n,tol}}\right| + \left|\frac{z_n}{z_{n,tol}}\right| + \left|\frac{\dot{y}_n}{\dot{y}_{n,tol}}\right| + \left|\frac{\dot{z}_n}{\dot{z}_{n,tol}}\right|\right]$$

$$\psi_{tol} = \theta_{tol} = \phi_{tol} = \pm 10^\circ$$

$$y_{n,tol} = z_{n,tol} = \pm 1 \text{ ft } (0.3 \text{ m})$$

$$\dot{y}_{n,tol} = \dot{z}_{n,tol} = \pm 0.5 \text{ ft/sec } (0.15 \text{ m/s})$$

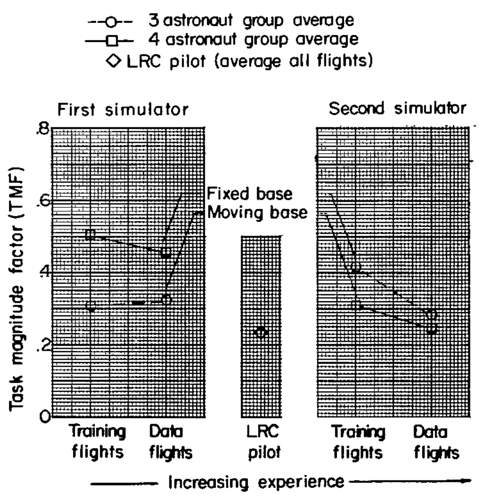


Figure 18.- Compressed learning curves for the various end conditions expressed as a single entity, a task magnitude factor. LRC pilot results shown for comparison.

in-tolerance conditions for $\dot{x}$ was not of comparable difficulty with the other variables. (Note, the $\dot{x}$ tolerance was never exceeded in these flights.)

As defined, a task magnitude factor of zero would represent perfect terminal values, a condition that is obviously impossible to achieve. However, some minimum value of TMF (considerably less than 1.0) can be expected after sufficient training, since all of the participants tried to achieve the best end conditions possible for each flight. A value of task magnitude factor was computed for each docking flight and the individual values were then combined to form the learning curves in figure 18. The experience scale has been compressed (in comparison to the previous figures) to show simply the training and data flight subdivisions of the test program. Docking flights that were lost are included in the data summations and were penalized by assigning such flights a TMF value of 1.0. Lost flights affect primarily the TMF values of the four-astronaut group on the fixed-base simulator (first simulator).

Comparison of first-simulator results of figure 18 for the two groups of astronauts shows that larger values of TMF were obtained on the fixed-base simulator. Relative alinement angles (ψ, θ, and ϕ) were the major contributors to these larger values. Of particular significance is the good agreement of the fixed- and moving-base TMF values for the data flights on the second simulator. In addition, both values are in agreement with the low value obtained by the research pilot. These results indicate that a learning effect exists in the magnitudes of the terminal values achieved on the fixed-base simulator.

Time-History Results

To provide some measure of the overall docking maneuvers employed from flight initiation to flight termination, the following information was obtained from the time-history traces for each docking flight:

(1) The largest positive and negative values of displacement and velocities (both linear and angular) were obtained following recovery from the initial conditions.

(2) An integrated average was obtained over the trajectory for each of the three attitude angles ψ, θ, and ϕ. (Positive and negative values were integrated separately.)

(3) The total fuel used and the components used for attitude and translation control were obtained at a number of specified points along the trajectory.

Average values for each of the preceding variables were obtained for the training, data, and extra docking flights made by each astronaut on each simulator. The resulting values were then combined to determine the three-astronaut and four-astronaut group averages presented herein. (See table I, fig. 19, and fig. 20.)

TABLE I.- GROUP AVERAGES OF LARGEST POSITIVE AND LARGEST NEGATIVE VALUES (MAXIMUM AND MINIMUM) OF FLIGHT VARIABLES ATTAINED DURING DOCKING TRAJECTORIES

(a) First simulator

		ψ, deg	θ, deg	ϕ, deg	y		z		$\dot{x}$		$\dot{y}$		$\dot{z}$		p, deg/sec	q, deg/sec	r, deg/sec
					ft	m	ft	m	ft/sec	m/s	ft/sec	m/s	ft/sec	m/s			
Four-astronaut group; fixed-base simulator																	
Training flights	Max.	15.1	14.5	21.6	4.9	1.49	9.5	2.90	0.74	0.23	0.30	0.09	0.27	0.08	6.0	3.3	3.4
	Min.	-10.1	-9.8	-31.4	-6.7	-2.04	-4.0	-1.22	-.27	-.08	-.32	-.1	-.28	-.09	-6.9	-2.9	-2.5
Data flights	Max.	9.0	9.5	13.2	3.1	0.94	5.2	1.58	0.89	0.27	0.26	0.08	0.21	0.06	6.1	2.5	2.5
	Min.	-7.9	-8.7	-18.8	-4.2	-1.3	-4.0	-1.22	-.35	-.11	-.20	-.06	-.28	-.09	-5.9	-2.3	-2.4
Extra flights	Max.	8.5	7.8	11.6	2.7	0.82	5.7	1.74	0.86	0.26	0.24	0.07	0.20	0.06	5.7	2.1	2.9
	Min.	-8.0	-9.5	-17.6	-5.7	-1.74	-2.6	-.79	-.57	-.17	-.26	-.08	-.27	-.08	-5.4	-2.3	-1.0
Three-astronaut group; moving-base simulator																	
Training flights	Max.	8.9	5.5	11.9	3.4	1.04	2.5	0.76	0.90	0.27	0.20	0.06	0.30	0.09	2.4	1.8	1.7
	Min.	-6.3	-8.2	-4.2	-1.6	-.49	-1.9	-.58	-1.6	-.49	-.19	-.06	-.19	-.06	-2.5	-1.9	-1.4
Data flights	Max.	7.4	4.4	11.1	3.0	0.91	4.0	1.22	1.30	0.40	0.39	0.12	0.26	0.08	2.3	1.7	1.3
	Min.	-6.5	-9.1	-6.5	-1.9	-.58	-1.6	.49	-.11	-.03	-.18	-.05	-.15	-.05	-2.3	-1.8	-1.3

(b) Second simulator

		ψ, deg	θ, deg	ϕ, deg	y		z		$\dot{x}$		$\dot{y}$		$\dot{z}$		p, deg/sec	q, deg/sec	r, deg/sec
					ft	m	ft	m	ft/sec	m/s	ft/sec	m/s	ft/sec	m/s			
Three-astronaut group; fixed-base simulator																	
Training flights	Max.	11.6	11.4	14.9	5.9	1.80	5.7	1.74	0.92	0.28	0.22	0.07	0.22	0.07	3.1	2.2	2.0
	Min.	-6.5	-9.4	-17.1	-5.4	-1.65	-2.8	-.85	-.24	-.07	-.22	-.07	-.21	-.06	-4.0	-1.6	-1.8
Data flights	Max.	7.7	7.1	10.6	1.8	0.55	3.3	1.01	1.08	0.33	0.20	0.06	0.17	0.05	3.1	1.7	1.3
	Min.	-6.7	-8.1	-10.2	-3.5	-1.07	-2.5	-.76	-.18	-.05	-.22	-.07	-.24	-.07	-4.2	-1.8	-1.3
Extra flights	Max.	5.5	7.3	13.9	5.1	1.55	4.8	1.46	1.18	0.36	0.32	0.09	0.19	0.06	4.0	1.4	1.6
	Min.	-11.4	-8.0	-14.4	-4.6	-1.40	-2.9	-.89	-.08	-.02	-.18	-.05	-.26	-.08	-4.0	-1.7	-1.9
Four-astronaut group; moving-base simulator																	
Training flights	Max.	6.8	7.8	9.4	3.4	1.04	2.4	0.73	0.71	0.22	0.19	0.06	0.21	0.06	3.1	2.3	1.5
	Min.	-6.8	-9.6	-8.0	-1.8	-.55	-2.5	-.75	-.09	-.03	-.17	-.05	-.20	-.06	-2.7	-2.2	-1.4
Data flights	Max.	5.1	3.3	6.9	2.7	0.82	2.5	0.75	0.65	0.20	0.12	0.04	0.15	0.05	2.2	1.3	0.9
	Min.	-5.0	-6.8	-7.2	-1.8	-.55	-3.9	-1.19	-.07	-.02	-.57	-.17	-.17	-.05	-2.3	-1.3	-1.0

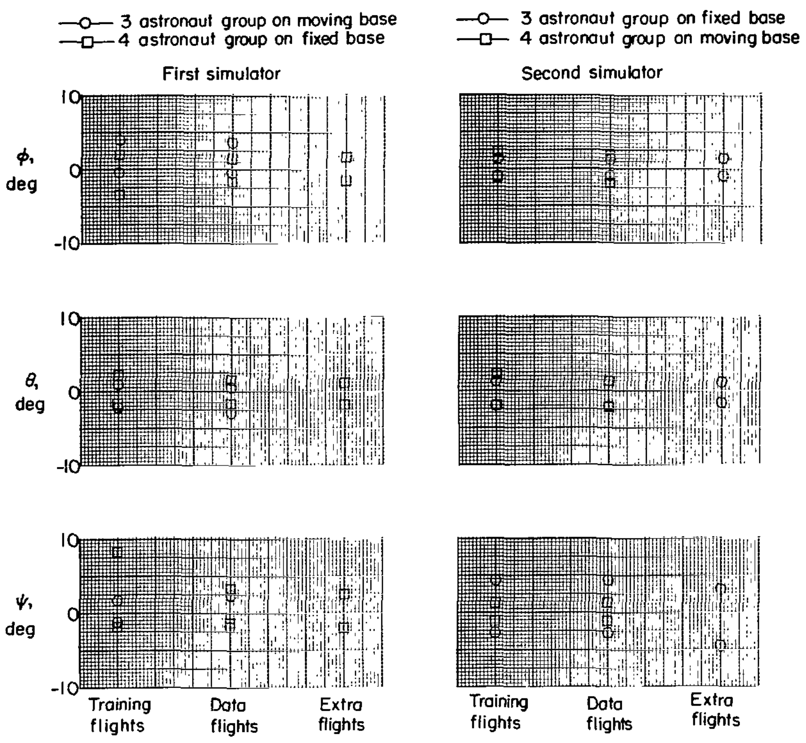
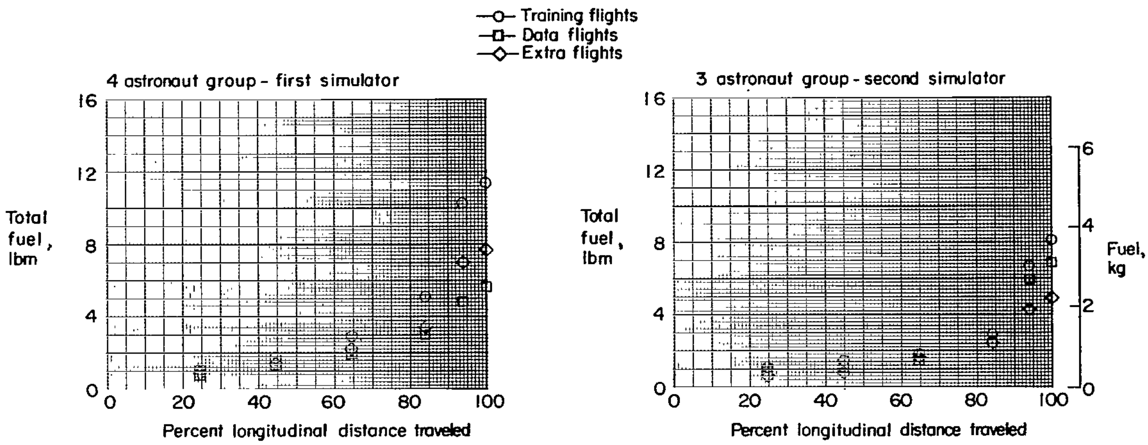


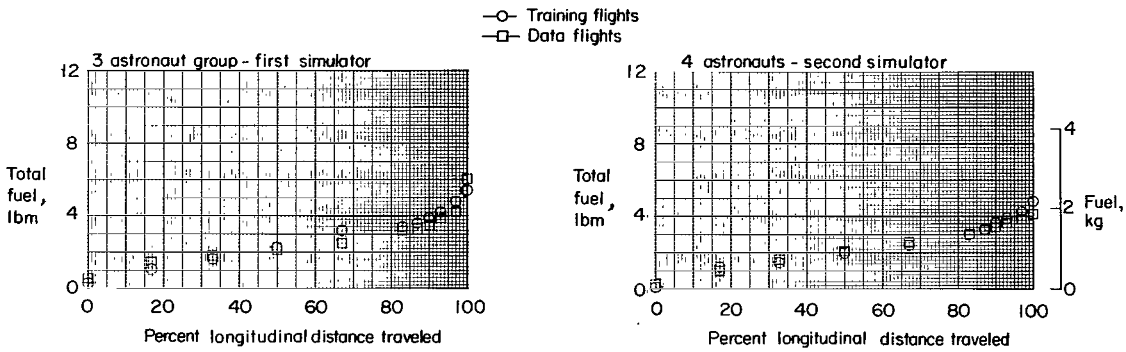
Figure 19.- Integrated averages over trajectory for the three attitude angles (positive and negative values integrated separately).

Examination of the maximum values for the various flight variables in table I show for a fixed- versus moving-base comparison that, in the majority of cases, larger excursions occurred for the docking flights on the fixed-base simulator. In fact in only about one-sixth of the available comparisons are larger excursions noted for the moving-base simulator. One of the largest differences existing in the values of a given variable for the two simulations is in the roll angle for the first simulators flown. The large angles shown for the fixed-base simulator probably would never be experienced in the moving-base simulator because of the presence of the gravity-force angular cue. In spite of the larger excursions on the fixed-base machine, the integrated averages for the attitude angles are in reasonable agreement for both simulators, particularly for the data flights. (See fig. 19.) Other than one or possibly two larger excursions per flight on the fixed-base simulator, the magnitudes of the angles must have been comparable over most of the trajectory with those of the moving-base simulator in order to produce the comparison shown.

Fuel consumed during the docking maneuvers from flight initiation to termination varies approximately linearly with longitudinal displacement in both simulators for about 80 percent of the distance traveled. (See figs. 20(a) and (b).) For the final 20 feet (6.09 meters) or so prior to flight termination, an increase in fuel consumption is evident in the results for both simulators, however, the effect is more pronounced for the fixed-base simulator. Component fuel variations (not presented) for translation and attitude control are very similar to those shown for total fuel used. Comparison of fixed- and moving-base fuel results for the data flights (fig. 20(c)) shows similar trends in the results for most of the trajectory.



(a) Fixed-base simulator results.



(b) Moving-base simulator results.

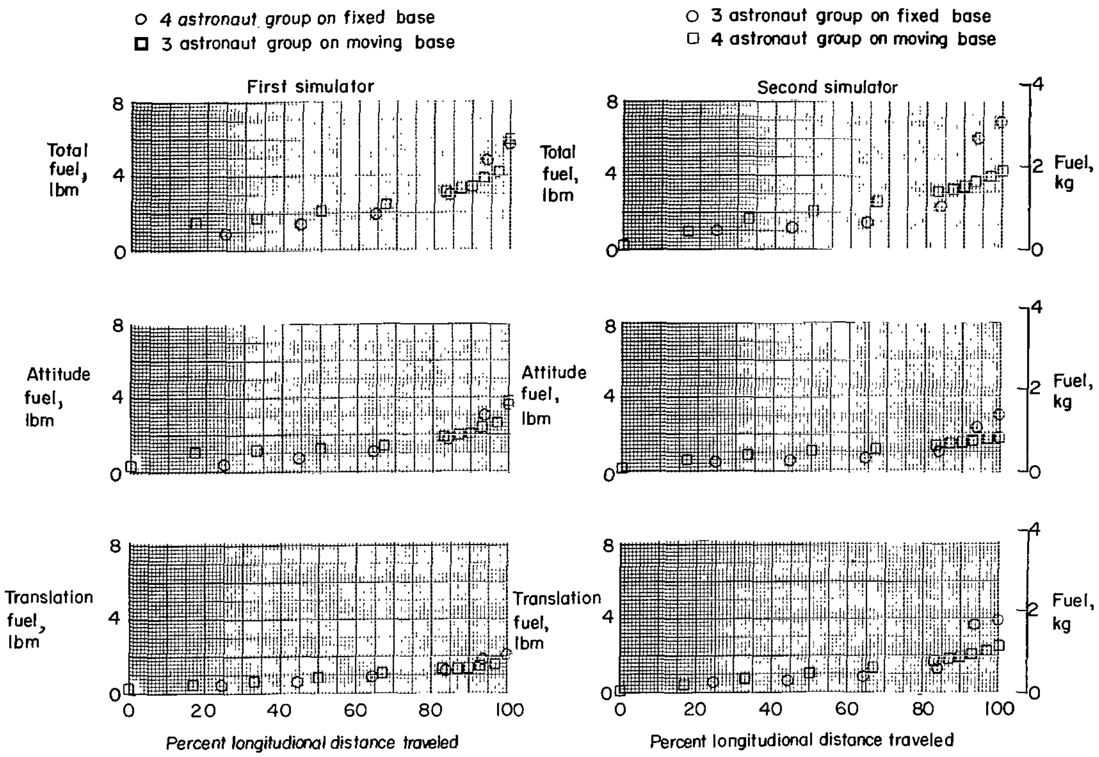
Figure 20.- Fuel consumption as a function of longitudinal distance traveled showing fixed- and moving-base test results and a comparison of data-flight fuel values.

Pilot Contributions

Pilot opinions.- Debriefings were held immediately after each test session. A questionnaire having approximately 30 entries was employed. The majority of questions submitted were identical for the two simulations. In addition, after completing the debriefing questionnaire on the second simulator, an extra group of questions was asked concerning both simulations. Appendix A contains most of the questions used, a summary of the answers, and pertinent comments. In addition to its usefulness herein, some of the information contained in appendix A is of particular interest to Gemini-Agena docking.

A few of the major observations of the participants concerning the simulator correlation are listed below:

(1) The tasks were very nearly identical.



(c) Comparison of data-flight fuel consumption values between astronaut groups for first and second simulator tests (translation and attitude fuel values combine to form total fuel used).

Figure 20.- Concluded.

(2) The same docking-maneuver techniques were employed in both simulators.

(3) The maneuvering cues obtained in both simulators were nearly the same. The fixed-base simulator lacked three-dimensional cues for the final 10 to 20 feet (3.05 to 6.09 meters) of the closure. The moving-base simulator had false body-motion cues, particularly in roll.

(4) The response characteristics of the two simulators were not the same. Larger lags were associated with the moving-base simulator.

(5) At any given range, the target was more vivid (that is, clarity and sharpness of detail) in the moving-base than in the fixed-base simulator.

Pilot ratings.- The seven astronauts and the research pilot evaluated the two simulators. The Cooper rating schedule of reference 10 was employed. (See table II.) This schedule was developed at the Ames Research Center for evaluating airplane handling qualities and stability and control characteristics and was used herein because of its general applicability.

TABLE II.- COOPER PILOT OPINION RATING SCHEDULE

Adjective rating	Numerical rating	Description	Mission accomplished
Satisfactory	1	Excellent, includes optimum	Yes
	2	Good, pleasant to fly	Yes
	3	Satisfactory, but with some mildly unpleasant characteristics	Yes
Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes
	5	Unacceptable for normal operation	Doubtful
	6	Acceptable for emergency condition only[1]	Doubtful
Unacceptable	7	Unacceptable even for emergency conditions	No
	8	Unacceptable – dangerous	No
	9	Unacceptable – uncontrollable	No
Catastrophic	10	Motions possibly violent enough to prevent pilot escape	No

[1]Failure of a stability augmenter.

The following table shows ratings of simulators by the astronauts and the research pilot:

Simulator	Rating by astronaut –							Astronaut average rating	Research pilot rating
	A	B	C	D	E	F	G		
Fixed base	4	$1\frac{1}{2}$	3	$3\frac{1}{2}$	3	4	3	3.14	3
Moving base	4	$1\frac{1}{2}$	2	2	1	$3\frac{1}{2}$	1	2.14	2

Astronaut ratings for the overall characteristics of the two simulators varied from 1 to 4. The average ratings, however, show a one point preference for the moving-base simulator.

Evaluation

A comparison of the results obtained from the two simulations indicates the following similarities:

(1) The piloting tasks were nearly identical.

(2) Basic piloting techniques employed were the same. (An analysis of the attitude and translation fuel used during docking supports this statement.)

(3) Group performance results (consisting of percent success, fuel consumption, and flight time required), after training, were in good agreement.

(4) End conditions achieved, when combined to form a single entity, were in agreement after sufficient training.

(5) Time-history results were comparable.

These results indicate that either simulator can be used for the docking task and, after sufficient training of the pilot, provide essentially the same performance data and end conditions. (Some training is required, but the amount is different for the two simulators as indicated by the learning effects in the fuel-consumed and flight-time data.)

A pronounced learning effect was apparent in the "percent-success" data of the fixed-base simulation which indicated that the astronauts had more difficulty learning to achieve in-tolerance terminal conditions with this simulator. Achievement of desirable terminal conditions is dependent to a large extent on the maneuvers executed in the final few feet of separation. Several differences in the simulations make it difficult to pinpoint the specific factor or factors producing the learning effect. The target docking cones and target markings employed were not identical and hence the visual cues, although similar, were not the same. Undoubtedly the fact that the TV image is only a degraded version of the actual vehicle (as regards clarity and sharpness of detail), as well as the lack of three dimensionality that existed in the television presentation are important factors in producing the learning effects obtained. The major influence on percent success of lost flights on the fixed-base simulator would be early in the test program when the subject was getting acquainted with control coupling and vehicle dynamics. The presence of body-motion cues in the moving-base simulator would be of additional help in eliminating large excursions and avoiding loss of control. The use of the gravity-force angular cues to achieve desirable terminal conditions were of less significance in the final few feet of the docking maneuver where visual cues predominate.

Advantages and disadvantages exist for each of the simulators as applied to the study of space flight docking. The more important ones are as follows:

Fixed-base simulator with TV	Moving-base simulator
Advantages:	Advantages:
(1) Large maneuvering range	(1) Uses full-size three-dimensional target (can employ actual design hardware)
(2) No variable-gravity-force cues	(2) Duplicates exact visual cues

Disadvantages:	Disadvantages:
(1) Lack of three dimensions at close range	(1) Limited operational volume
(2) TV degrades target visual cues	(2) False gravity-force cues with angular orientation (particularly roll)

Of the two simulators, the astronauts preferred the moving-base simulator, because of the better visual cues available. Overall assessment of the simulations on the basis of operational volume and investigative usefulness for the docking task indicates that the two simulators are complementary.

CONCLUDING REMARKS

An investigation has been made to assess the overall compatibility of the results of two independent full-size six-degree-of-freedom simulations of pilot-controlled Gemini-Agena docking. One simulator (fixed base) employed closed-circuit television to display a full-size image of the Agena target vehicle to the pilot. The other simulator (moving-base) used a movable full-size model of the Gemini spacecraft and a stationary three-dimensional Agena target. Seven astronauts who had not flown either simulator and who were untrained in Gemini-Agena docking served as the test subjects. Docking flights were made by using the direct (backup) mode of control with only visual observation of a fully illuminated target for guidance.

The data of the present investigation indicate that, after sufficient training, similar docking results can be obtained with either simulator. Learning effects were found for both simulations; however, these effects were considerably more pronounced for the fixed-base simulator. Differences in the target markings and docking cones employed on the Agena models, a lack of three dimensions in the TV image, degradation of the visual cues due to the TV presentation, and the presence of the gravity-force angular cue in the moving-base simulator are partially responsible for this difference in learning effects.

The significance of the simulator comparison is in illustrating that, in the case of two sophisticated simulations of a docking problem, large differences in learning effects can be encountered, yet comparable numerical results can be obtained if sufficient training is employed.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 13, 1966.

APPENDIX A

ASTRONAUT DEBRIEFINGS

This appendix includes some of the questions presented to the astronauts during debriefing and a composite of the answers and pertinent comments.

1. For the initial conditions that you have flown, do you have a preferred technique for the maneuver?

   All participants: Yes.

   Two basic techniques (about evenly divided among participants) were evident for the initial conditions employed. One technique consisted of (a) initially rotating the spacecraft and aiming it so as to intercept the longitudinal axis of the target a short distance in front of the docking cone, (b) firing the longitudinal thrusters to establish a closure rate, (c) null relative attitudes during the coasting period, (d) fire vertical and/or lateral thrusters to remove transverse velocity at intercept point, and (e) null transverse displacements and angular misalinements from intercept point to termination point.

   The other approach consisted of (a) nulling the attitudes initially, (b) firing the translational thrusters in the x, y, and z directions to initiate a closure trajectory, (c) fire transverse thrusters to remove transverse velocities at intercept point, and (d) null errors as they develop into the flight termination point.

   Several participants indicated they preferred a position slightly high and somewhat to the left during the final approach (following intercept point) in order to utilize changes in target aspect better.

2. Would you change this technique if you were making one of the first docking maneuvers in space?

   All participants: No, assuming similar conditions existed such as no instruments, similar targets, and comparable target lighting.

3. Are there cues in these simulations that are false and do not truly represent the zero "g" condition?

   Fixed-base simulator: Pilot is under a constant 1g field. The control task, however, is not influenced by the gravity field since the target moves. In addition, a lack of acceleration forces from the thrusters exists. Also a fixed eye position is employed. (Note, absence of display movement due to pilot's head motions is probably noticeable only when the target is near the line-of-sight through the index bar.)

   Moving-base simulator: Pilot experiences false gravity cues due to angular orientation (particularly in roll) that can aid in control during the flight. In addition, input-output lags are noticeable.

4. Is your closure technique affected in any way by the simulator itself?

   Majority reply: No, initial conditions are idealized in that small displacements (near center-line conditions) and zero velocities were employed and may affect technique.

   Fixed-base simulator: Technique may be influenced somewhat because of picture quality and lack of three dimensions.

   Moving-base simulator: Possibility exists of some minor influence due to presence of lags.

5. Do you feel that any limitations have been placed on your maneuvering requirements in either simulator?

   All participants: For initial conditions employed, no.

6. Are you able to perform maneuvers smoothly in each simulator?

   All participants: Yes. Practice is required.

7. Do you obtain maneuvering cues in both simulators in the same manner?

   Majority reply: Yes.

   Translation cues are from apparent change in target size and aspect. Comparable visual cues are obtained at a greater range in moving-base simulator.

8. Do you use the same approach technique in both simulators?

   Majority reply: Essentially the same.

9. After flying both simulators do you feel the tasks are identical? If not, would you define differences.

   All participants: Tasks essentially identical. Differences are lag and "1g" roll cue in moving-base simulator. Control task is more difficult in fixed-base simulator because of picture quality and lack of three dimensionality.

10. Does this simulator provide adequate responses?

    Moving-base simulator: All participants indicated yes.

    Fixed-base simulator: All participants indicated yes.

11. Do both simulators have the same response characteristics?

    Four participants: About the same.

    Three participants: No, more lag in moving-base simulator.

12. Do you use motion cues as stimuli?

Several participants: Yes.

Several participants: No.

13. Not having flown the fixed-base simulator, do you feel that motion cues are an advantage or disadvantage in learning to fly the moving-base simulator mission? (Only three replies.)

One participant: "Neither – you do get a "g" cue in roll, but adequate visual aids are available anyway."

Two participants: Yes.

"Motion per se doesn't do anything for you. Motion cues with respect to the target are useful."

14. Do you feel that the moving vehicle provides an added incentive to maintaining precise control?

Five participants: Yes.

One participant: Don't believe so.

One participant: Possible – it is a small effect and may exist.

15. Do you think the fact that your cockpit moves helps you separate attitude changes from translations?

Five participants: Yes, of these one was definite, one indicated that it helps, and one was not sure if it was a significant effect. No comments were made by other two participants.

One participant: It might indirectly help.

One participant: "No, not during final alinement for which only visual cues are used.

16. Does the TV image give adequate representation of a full-scale Agena flight vehicle?

Majority reply: Yes, within limits of knowledge at present time, but not as good as the real item.

Remaining participants: Not sufficiently familiar with Agena configuration to comment at this time.

17. Does the TV presentation give an adequate representation of the target vehicle at (a) maximum range? (b) half range?

General consensus: At maximum range the image appeared slightly hazy or blurred; at half range it was about as could be expected from TV; and in close it was adequate, strictly two dimensional, but fairly realistic. However, it lacked depth which is desirable for docking maneuvers.

18. How do the two simulators compare as to vividness (sharpness and clarity) of target: (a) from 125 ft (38.1 m)? (b) from 10 ft (3.05 m)? (c) from 3 ft (0.9 m)?

All participants: Moving-base simulator's target was more vivid at all ranges.

19. How far away can you line up the target in the simulators?

A synthesis of replies indicates that alinement could be made at maximum range of 125 feet (38.1 m) for both simulators. At this range, the accuracy of attitude alinement was reasonably comparable between the two simulators, however, translational alinement accuracy was superior in the moving-base simulator. Image quality of the TV presentation in the fixed-base simulator at maximum range was such that a reduction of range by roughly 25 percent was required to establish confidence in the translational alinement.

20. How do you obtain your velocity information from out-of-the-window references?

General consensus for both simulators: Change in target aspect provides transverse velocities. Change in target size for closure velocity.

For close-in operation, depth perception was a definite advantage of moving-base simulator. Depth perception was useful for closure velocity and distance to go.

21. What gives you the clues for alining yourself just prior to contact?

General consensus for both simulators: Index bar and V-slot provide roll clues. Pitch and yaw are nulled by inspection of crescent-shaped area of docking ring visible above Gemini nose.

Alinement of pilot's eye, comparable 10:00 o'clock position on target docking ring, and anticipated location of aft end of booster provides translational positioning. This alinement requires final approach to be slightly to left and slightly high in order to anticipate location of booster aft end. When slightly to right and low, translational alinement is difficult.

22. Can you recognize small rates apart from small translational velocities? How? (Roll rate and closure rate were considered obvious.)

Four participants said they thought they could. Changes in target aspect are translational velocities. Angular rates obtained by position of Gemini nose with respect to target vehicle with no aspect change occurring. In general, the angular rates were larger than translational velocities and relative magnitudes could be used to help in separating them. Three participants indicated that the differences between the small rates and velocities were difficult to recognize for the Agena configuration presented. "If they are small it did not appear necessary to recognize which is which. If large they can be differentiated."

23. Do you feel that you can complete docking without backing off and trying again?

Majority reply for both simulators: Yes, with sufficient practice. "This is more a function of practice than anything else."

24. Do you feel that you can stay consistently within ±5 feet (±1.5 m) vertically and laterally from 125 feet (38.1 m) to contact? If so, from what do you obtain your information?

Majority reply for both simulators: Yes. Several replies, however, were qualified to indicate that visual aids for translational alinement would be required for certainty. Information cues were obtained from target aspect.

25. How closely are you able to control the moving-base vehicle to the position and rate you want?

Majority reply: Position and rates could be controlled adequately. Control coupling complicates the task. Practice will provide improvement. Very small inputs are difficult to obtain.

26. How closely do you think you can judge your position from 5 feet (1.5 m) away to contact?

Moving-base simulator: Within 6 inches (15 cm) in x, y, and z – you could judge better than you could control it.

Fixed-base simulator: About 6 inches (15 cm) in y and z – it was difficult to tell exact longitudinal point of flight termination.

27. What do you consider the most critical point in the approach?

All participants: Last 2 to 5 feet (0.6 to 1.5 m) of maneuver.

28. What is the most difficult task near contact – positioning laterally and vertically or maintaining attitudes within tolerances?

Majority of participants indicated that it was difficult to answer because of the interplay between the two (cross coupling) and the fact that attitude errors were sometimes intentionally generated to minimize effects of position errors rather than correct the position errors because of coupling. For the fixed-base simulator the majority reply was positioning laterally and vertically. (Boresight alinement in the fixed-base simulator was apparently recognized by most of the participants as the factor causing angular alinement difficulties.)

29. Do you find yourself trying to control the target vehicle in either simulator and not the Gemini?

	No	Yes
Fixed-base simulator	6	1 (occasionally)
Moving-base simulator	7	0

30. Is there any point at which you begin to use the three-dimensional visual cues provided by the target cone on the moving-base simulator and if so, at what relative distance does this occur?

Three participants indicated that they did not use three-dimensional cues of target cone but rather the target body. Four participants indicated that good cues were available inside of 10 feet (3.05 m) and they were most useful in this range.

31. Do you feel that starting from a range of 300 feet (91.4 m) instead of 125 feet (38.1 m) would affect the docking maneuver?

All participants: No. Fuel and flight time would increase due to extra maneuvering required.

32. Do you feel that it is more difficult to fly from 300 feet (91.4 m) than 125 feet (38.1 m)?

All participants: No.

33. After being trained on one simulator and you miss the tolerances on the first few runs on the second simulator, do you feel the reason is associated with the simulator or yourself?

Majority reply: Due to differences in the simulators as, for example, in responses and in visual cues.

34. Do you prefer a moving-base simulator or a fixed-base simulator as a trainer for the docking phase?

Moving base	Fixed base	Either one
4	0	3

Moving-base proponents indicated that it was more realistic and it provided three-dimensional cues. Remaining participants indicated that there were advantages and disadvantages to each and that either would suffice as a trainer if TV were improved on fixed-base simulator or lags reduced on moving-base simulator.

35. Do you consider this type of correlation study to be a good method of comparing two simulators?

Six participants: Yes.

One participant indicated it is sufficient for a simulator comparison but also noted that a strict fixed- versus moving-base comparison should not involve TV versus real target but should use the identical target in both.

36. Do you have as much confidence in the visual docking maneuver as you do in a visual landing with a familiar airplane?

Majority reply: No, not at present stage of training – with sufficient practice, yes.

37. What physiological effects do you think result from the present schedule due to: (a) overnight layoff? (b) length of each session?

(a) All participants: None.

(b) All participants: None, the sessions were a little long. Longer session length is probably undesirable because of eye strain, however, the effects of learning far outweigh physiological effects.

38. How long do you think you can retain the level of proficiency learned here?

General consensus: Probably begins to drop off slowly in several days, however, it can be picked up quickly again.

Several participants estimated they could probably retain about 90 percent efficiency for making successful dockings for about 3 to 4 weeks.

39. Do you think you were asked to fly too many runs in either session?

All participants: No.

Fixed-base simulator session: 22 to 34 flights, average 27.

Moving-base simulator session: 15 to 25 flights, average 20.

40. Do you think any visual aids are required on Gemini or Agena or both?

Four participants: For fully illuminated target, visual aids are not required but their use for translational alinement strongly recommended.

Three participants: Yes, additional boresight information needed.

41. Is the design deadband in the attitude hand controller satisfactory?

Majority of participants: All right. Deadband limits have to be set for pressurized glove operation.

42. Are the breakout and force levels for both controllers satisfactory?

Attitude controller: All participants indicated satisfactory.

Translation controller: All participants indicated unsatisfactory – force levels and gradients too high in all three directions and unsymmetrical.

(Note, the unsatisfactory comments on the translation controller were anticipated from results of ref. 5. The present study was conducted subsequent to the tests of ref. 5 and modifications to the translation controller to improve its characteristics were not accomplished. The controller has since been modified to eliminate the objectionable features of looseness in the mechanism, uneven forces about each axis, and some binding when deflected. Although some features of the translational controller were undesirable, the device was operational and its deficiencies had only minor effects on the docking task required herein.)

43. Give a Cooper rating for the attitude controller. (Ratings were obtained following tests on each simulator. For rating schedule see table II.)

Simulator	Rating by astronaut –							Astronaut average rating	Research pilot rating
	A	B	C	D	E	F	G		
Fixed-base	3	2	3.5	2	2	3	2	2.50	1.5
Moving-base	3	1	3	3	2	3	2.5	2.50	---

44. Give a Cooper rating for the translation controller. (Ratings were obtained following tests on each simulator. For rating schedule, see table II. Also note comments of question 42.)

Simulator	Rating by astronaut –							Astronaut average rating	Research pilot rating
	A	B	C	D	E	F	G		
Fixed-base	6	4	6	3	3	4	3	4.14	2.5
Moving-base	6	3.5	5	4.5	3	4	3	4.14	---

45. Is the translation control power adequate?

All participants: Yes.

One participant commented, "It is more than adequate – wouldn't want it larger."

46. Is the control power in the direct attitude mode satisfactory?

All participants: Yes.

47. What Cooper rating would you give the direct control mode: (a) for attitude? (b) for translation? (Ratings were obtained following tests on each simulator. For rating schedule, see table II.)

Attitude control

Simulator	Rating by astronaut –							Astronaut average rating	Research pilot rating
	A	B	C	D	E	F	G		
Fixed-base	3	3.5	4	5	2	3	3	3.36	2
Moving-base	*3	3	4	3.5	2	4	2	3.07	---

*Would be 2 without coupling.

Translation control

Simulator	Rating by astronaut –							Astronaut average rating	Research pilot rating
	A	B	C	D	E	F	G		
Fixed-base	3	3.5	3	4.5	2	3	4	3.29	3.5
Moving-base	3	2	2	3.5	2	3	3	2.64	---

48. What are your comments on direct control mode: (a) for the docking operation? (b) for other conceived control tasks?

(a) Several participants: Satisfactory as a backup mode. Others indicated direct mode entirely adequate for docking – no reservations about using it.

(b) Can be used for retrofire, reentries, and other maneuvers that do not require the maintenance of precise attitudes (such as required in navigational sightings).

49. What cockpit instruments do you think would be (a) necessary and (b) helpful for the docking maneuver?

(a) All participants: None, for fully illuminated target and initial conditions used herein. For actual spaceflight rendezvous and docking one subject indicated a fuel gage would be mandatory.

(b) Composite comment: Relative attitudes between spacecraft and target; spacecraft body rates; range rate; range.

Most participants indicated that additional instruments would be used as a quick-check reference for ranges less than 125 feet (38.1 m). They would be of more help at greater ranges.

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